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SOLID STATE KU-BAND POWER AMPLIFIER

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Jan. 1972
Final Report

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Technical Officer: W. E. Hughes, Code 811.4

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16. Abstract

Work done on Contract NAS 5-11388 is summarized. This includes design, fabrication and testing of two types of IMPATT diode reflection amplifiers and a transmission amplifier. Ku-band IMPATT diode development is discussed. Circuitry and electrical performance of the final version of the Ku-band amplifier is described. Construction details and an outline and mounting drawing are presented.

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PREFACE

This report summarizes the work done on NASA Contract NAS 5-11388. The objective of this contract was to develop a Ku-band IMPATT diode amplifier capable of a 1 watt output over a 100 MHz 1 dB bandwidth at 15 GHz with 20 dB gain. This included developmental work on two types of reflection amplifiers and a transmission amplifier, for use in the driver and output stages of the combined amplifier, and packaging of the final version of the amplifier. The effort during the first period was restricted to the design, fabrication, and preliminary testing of experimental versions of the three types of amplifers. Efforts during the second period included testing of improved diodes, and testing of the reflected and transmission amplifier circuits.

Work during the third period included testing of additional Ku-band diodes, further testing of the reflection and transmission amplifier circuits, and design and test of the DC bias and regulator circuitry. The one-diode reflection driver amplifier performed well and this work progressed according to schedule. The two-diode reflection and transmission power amplifiers did not perform quite as expected and were replaced with two single-diode reflection amplifiers.

INTRODUCTION

In this report we will summarize in some detail the work that has been accomplished on NASA contract NAS 5-11388 for a 1 watt, 20 dB gain, 15 GHz IMPATT diode amplifier. Specifically this will include descriptions of two types of reflection amplifiers and one transmission amplifier. In addition some information on Ku-band diodes and IMPATT diodes in general will be given. Since many of the techniques and design procedures used in this contract were developed under other programs, these programs will be referenced where appropriate, and the techniques and design procedures will be discussed. Electrical performance of the two amplifiers which were delivered will be discussed. Mechanical outline and mounting details of the amplifiers will be given.

KU-BAND DIODES

Since the IMPATT diode is the heart of the amplifier, it seems appropriate to discuss these diodes here even though the diodes were not developed as part of this program. Most diode development is funded under various company sponsored programs, and only fabrication costs are being covered by this contract.

Over the past several years Hughes Aircraft has been fabricating IMPATT diodes for use in many frequency ranges from X-band up to V-band and higher, and TRAPATT diodes from L-band to X-band. Power outputs of up to 2 watts have been obtained from single diodes in X-band, and several hundred milliwatts has been obtained at millimeter frequencies.

For designing new diodes or analyzing small signal characteristics of existing diodes, a small signal computer program is used. This program is quite detailed in nature and was developed some time ago on internal Research and Development funds. It is similar to the program described by Misawa.[1] Using this program we have calculated the small signal characteristics of a typical nearly abrupt junction silicon Ku-band IMPATT diodes. The admittance per unit area is shown in Figure 1. The admittance of a similar diode (51 volts breakdown) was measured in X-band on a network analyzer, and the results are shown in Figure 2. This measurement was performed under another contract from the Air Force Avionics Laboratory at Wright Patterson Air Force Base, F33615-69-C-1787. The measurement could not be continued into Ku-band because of limitations in the network analyzer facilities. The area of the diode measured is about 7.2×10^{-5} cm^2. Thus 75 milliamps bias corresponds to a current density of approximately 1000 $amps/cm^2$.

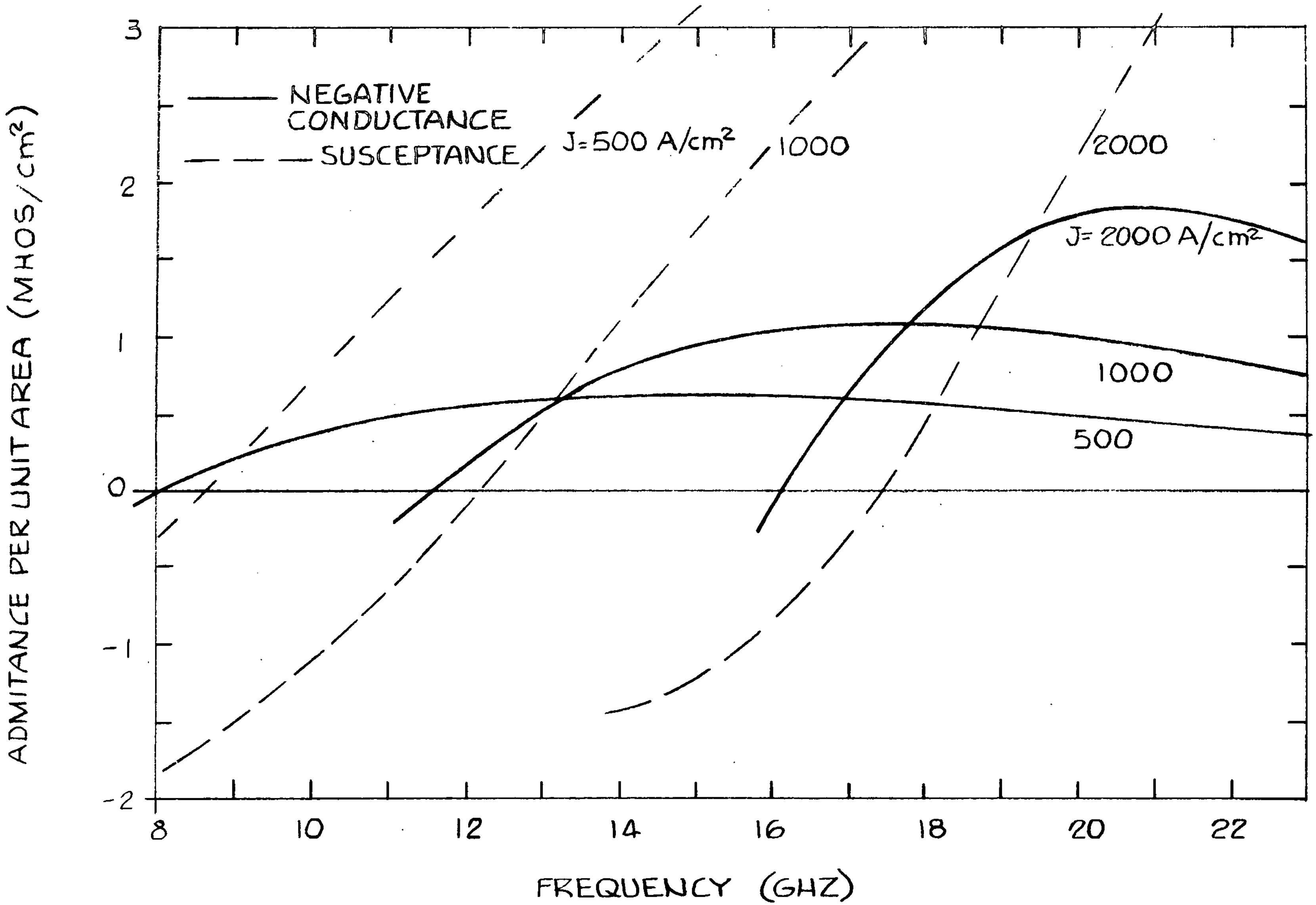

Figure 1 Theoretical admittance per unit area for 48.5 volt IMPATT diode.

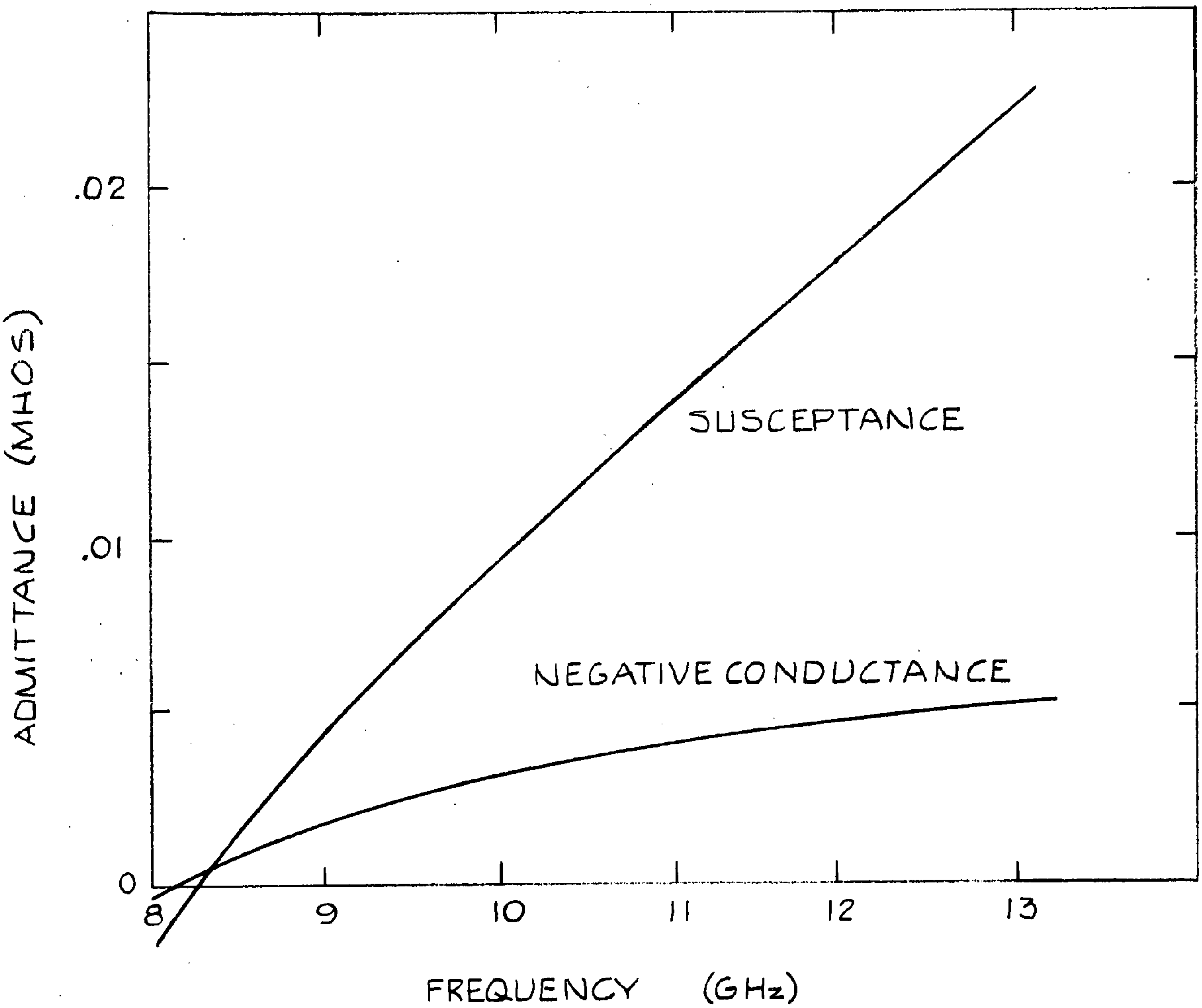

Figure 2 Measured X-band admittance of 51 volt IMPATT diode.

As can be seen from Figures 1 and 2 there is a considerable discrepancy between the experimental and theoretical admittance parameters, namely that the measured transit time resonance frequency is significantly lower than the predicted resonance frequency. We have found this to be the case with all diodes, and there is presently an effort in the Hughes research department to explain this discrepancy. It is believed that the differences are due to an error in the published values of ionization coefficients for silicon. These coefficients are of course extremely important and critical in the calculation of RF characteristics. The coefficients used in the calculations are those published by Crowell and Sze[2] for silicon and it is assumed that the junction operates at 200°C. It is felt that the error in this data is in the ratio of the hole ionization coefficient to that of the electrons.

However, by using the shape information in the theoretical curves, and the quantitative information in the experimentally measured curves, it is possible to extend the experimental curves into Ku-band. This can be done quite well because it has been found that the IMPATT diode junction can be modeled accurately by a parallel GLC circuit such as that in Figure 3. For the diodes under consideration we find that appropriate values for the circuit at 15 GHz are:

$-G = -0.005$ mhos
$C = 0.33$ pF and
$L = 1.08$ nH.

Placing the diode in a package introduces a series inductance and shunt capacitance, so that the equivalent circuit for the packaged diode is as shown in Figure 4. It is this model that is used for circuit design purposes, and to date all circuits have been designed on this basis.

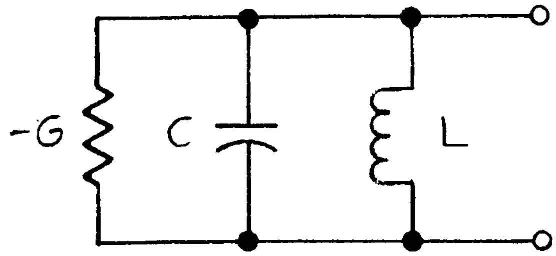

Figure 3 Equivalent circuit of diode junction.

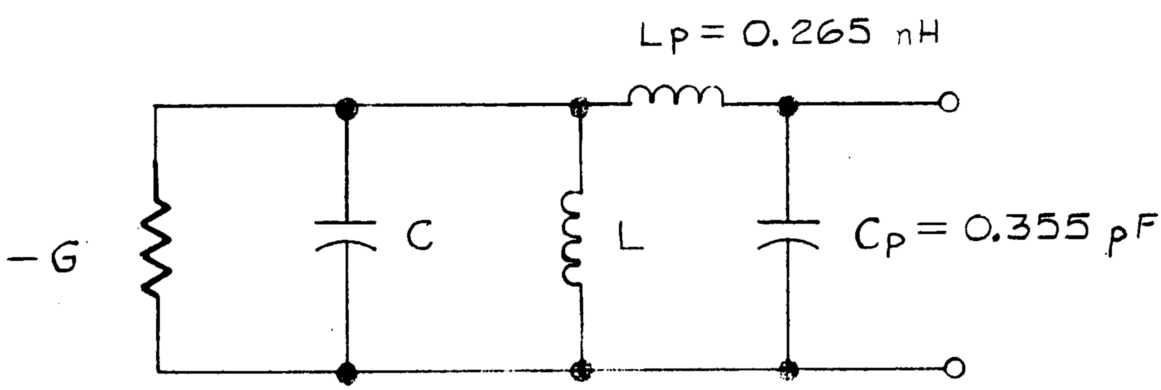

Figure 4 Equivalent circuit of packaged diode.

At the beginning of the program only a few wafers of relatively high voltage Ku-band material had been fabricated. During the program a number of silicon wafers were processed. The first group of these wafers did not yield acceptable Ku-band diodes. This was due to an uncertainty in the value of resistivity required to give the correct doping density and a contamination of the hydrogen used in the processing.

A subsequent group of silicon wafers were processed and some good material obtained. The diodes made from this material were used for the initial RF testing. They had breakdown voltages of about 40 volts and exhibited good dc/dV characteristics. At 15 GHz these diodes produced 11 dB gain at the 250 mW output power level and 2 dB gain at 500 mW output. This corresponds to a power generation of about 200 mW which was less than desired. These results were fairly small diodes and better results were expected for larger diodes. It was found that the initial Ku-band wafers processed were affected by contaminated silane which is used in the processing. This problem was corrected by our research laboratory and new material processed.

These wafers yielded better results than any of the previous diodes. The best of these diodes tested gave one watt output at 14 GHz as an amplifier with 5 dB gain. This corresponds to a generated power of 700 mW. Other diodes in this series can generate 300 - 600 mW at 15 GHz. Typical results obtained using the coaxial reflection amplifier are as follows:

OUTPUT POWER	GAIN	FREQUENCY
1 W	3 dB	15 GHz
500 mW	5 dB	15 GHz
150 mW	12 dB	15 GHz

These results indicated that it would be possible to construct the one watt, 20 dB gain 15 GHz amplifier using three coaxial reflection amplifier stages. It was not difficult to obtain 100 MHz or more bandwidth in this series of tests.

The diodes from which the above results were obtained are mounted in mini-disc packages (shown in Figure 5a) rather than standard packages (Figure 5b). It has been found that the diodes perform better at high power levels in the mini-disc packages than in the standard packages apparently because of the lower parasitics of the former. The highest power obtained from a Ku-band amplifier using a diode in a standard package is 900 mW with 3 dB gain at 14.7 GHz. The standard packaged diodes perform as well as mini-disc diodes under small signal conditions. For this reason diodes in standard packages which are sealed by high temperature brazing are used in the first stages of the amplifiers. Diodes in mini-disc packages which are sealed with gold-tin solder are used in the second and third stages. The diodes were burned-in for 90 hours in order to help assure reliability.

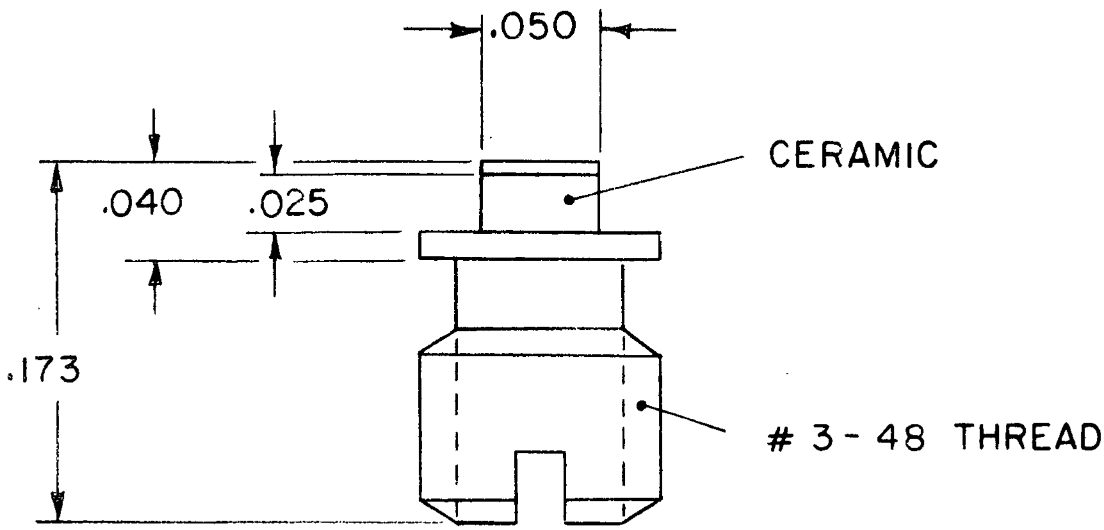

Figure 5a Mini-disc package.

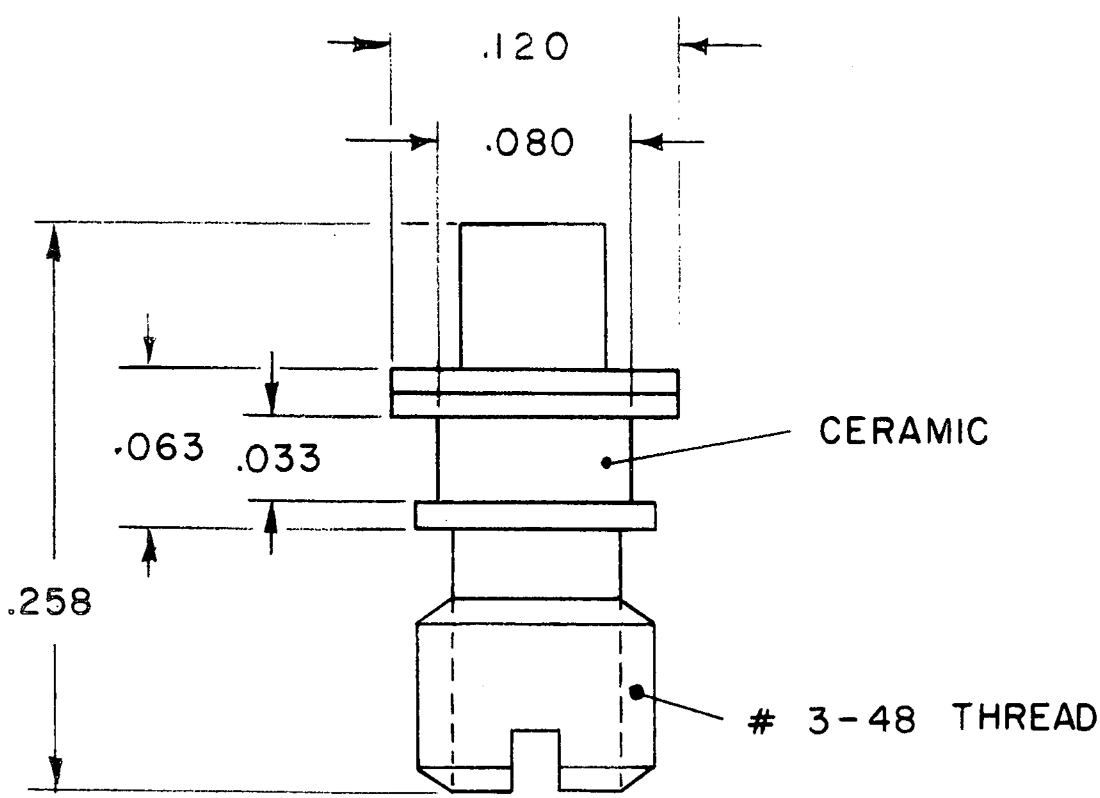

Figure 5b Standard package.

REFLECTION AMPLIFIERS

Very detailed procedures for designing reflection amplifiers have been developed under the Air Force contract previously mentioned. Many of the design procedures and techniques have been summarized by Matthaei et al[3] and we have expanded and computerized these techniques specifically for IMPATT diode amplifiers. Very simply stated, a reflection amplifier is designed and built by resonating the diode with a shunt or series length of line, calculating the Q of this structure, and providing the necessary impedance inverter or matching network based on this Q, the impedance level, and the desired gain and bandwidth.

One such circuit which is convenient for accomplishing this in TEM mode structures is that shown in Figure 6. Here the diode is shunt mounted at the end of the transmission line, a short length of series line brings the diode into resonance at the desired frequency, and a capacitor and two lengths of line serve as an impedance inverter. Such a circuit has been realized in a coaxial structure which is sketched in Figure 7. This circuit is particularly convenient in that the center frequency can be adjusted by sliding the capacitor along the line, and the gain can be adjusted by changing the size of the capacitor. Although this circuit was developed primarily for use in C and X-band, it has been found to work well through Ku-band. Because of its simplicity and flexibility it was used for testing diodes at Ku-band, and is used for all three stages in the final version of the Ku-band amplifier.

A detailed assembly drawing of the final version of the coaxial amplifier stage is shown in Figure 8. It shows the mounting of both types of diode packages, the matching capacitor and centering spacer, the 25 to 50 ohm step transformer, the bias circuit, the DC block and other mechanical details. The step transformer is present because it was found that the diodes could be made to operate at higher frequencies in the lower (25 ohm) impedance line.

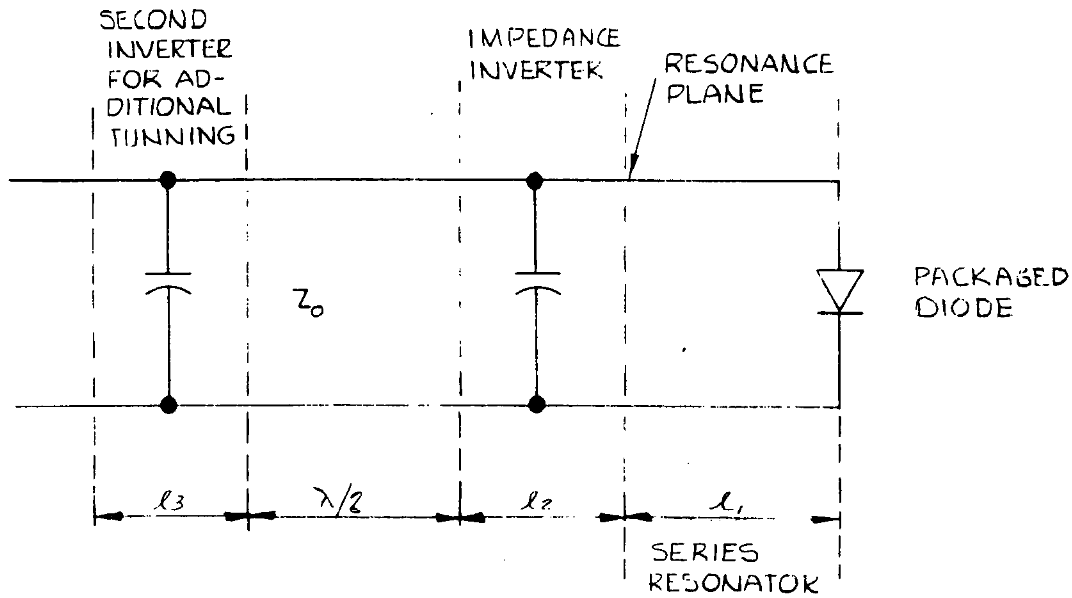

Figure 6 TEM mode amplifier configuration.

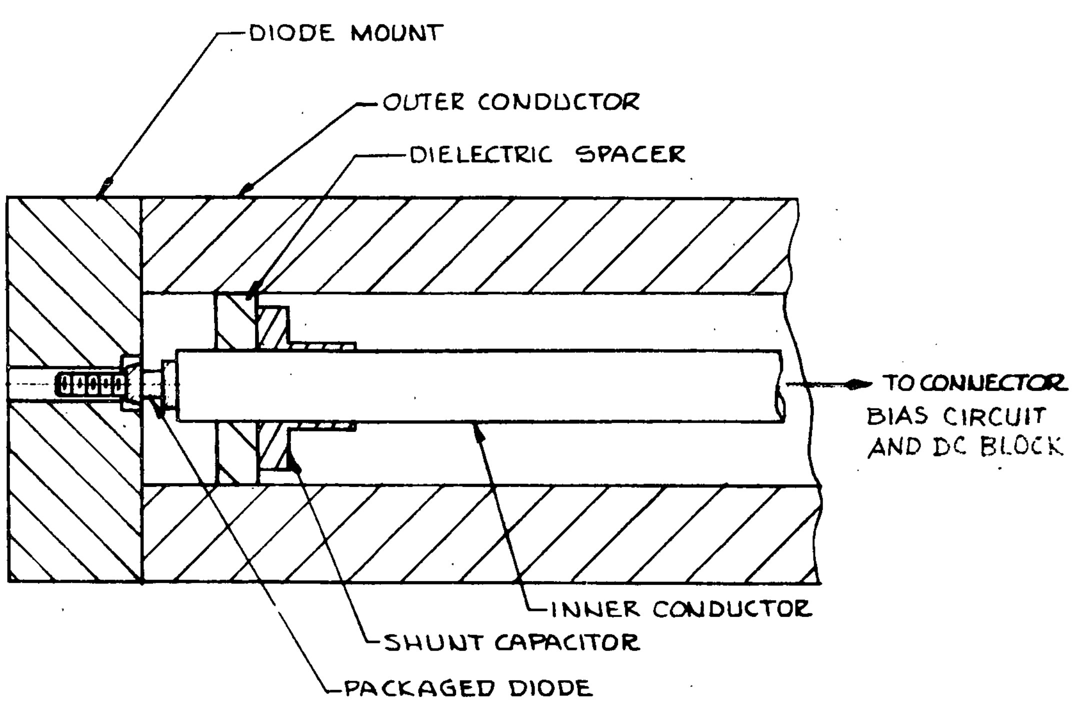

Figure 7 Coaxial reflection amplifier structure.

FOLDOUT FRAME 1 FOLDOUT FRAME 2

PART NO.	DEPICTED
B107734-001	AS SHOWN
-002	SEE NOTE 4
-003	AS SHOWN
-004	SEE NOTE 4

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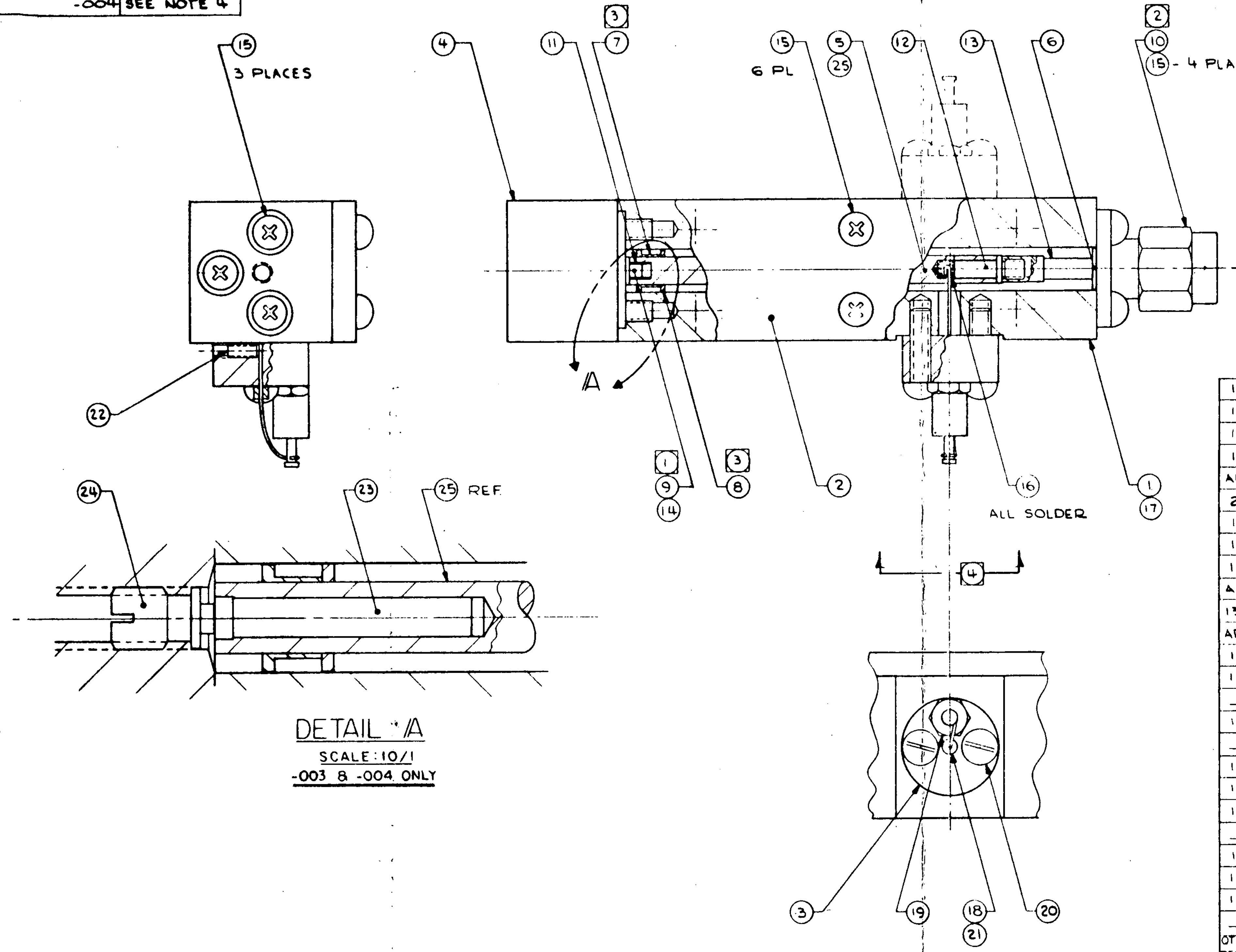

QTY REQD -004	QTY REQD -003	QTY REQD -002	QTY REQD -001	CODE IDENT	PART NO OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	ZONE	FIND NO.
1	1	—	—		B107968-001	CENTER CONDUCTOR, Ku PART C		25
1	1	—	—		A1201S-7	DIODE		24
1	1	—	—	PYLON CO.	ESF	POGO CONTACT		23
1	1	1	1			SCREW, SET, #0-80 x 1/8 LG		22
AR	AR	AR	AR			WIRE, .010 DIA COPPER		21
2	2	2	2			SCREW, TFE, #2-56 x 5/16 LG		20
1	1	1	1	USECO	MSTS-7	TERMINAL, INSULATED		19
1	1	1	1		B107970-001	BIAS WIRE BEAD		18
1	—	1	—		B107963-001	AMPLIFIER BODY, L.H.		17
AR	AR	AR	AR			SOLDER, COMP SN 60, TYPE RMA		16
13	13	13	13	ALL METAL SCREW	A140B0208	SCREW, RD HD, #2-56 x 1/4 LG		15
AR	AR	AR	AR	DOW CORNING	No 340	COMPOUND, SILICON HEAT SINK		14
1	1	1	1		B107967-001	CENTER CONDUCTOR, Ku PART B		13
1	1	1	1		B107966-001	DC BLOCK, CENTER CONDUCTOR		12
—	—	1	1		B117511-001	SOCKET, DIODE RECEPTACLE		11
1	1	1	1	OSM	OSM 214	CONNECTOR, R.F. (MODIFIED)		10
—	—	1	1		A1201V-H	DIODE		9
1	1	1	1		B106519-XXX	SPACER		8
1	1	1	1		B106520-XXX	CAPACITOR PLATE, INNER		7
1	1	1	1		B106534-001	SPACER, CENTER CONDUCTOR		6
—	—	1	1		B107969-001	CENTER CONDUCTOR, Ku, PART A		5
1	1	1	1		B106518-001	DIODE HOLDER		4
1	1	1	1		B107965-001	BIAS PLATE, TYPE II		3
1	1	1	1		B106523-001	TOP PLATE		2
—	1	—	1		B107964-001	AMPLIFIER BODY R.H.		1

PARTS LIST

NOTES:

4. BIAS PLATE ASSY IS LOCATED 180° CW (DASH LINE) FOR -002 & -004
3. ITEMS 7 & 8 ARE CHOSEN AS REQ'D TO MATCH DIODE
2. CENTER PIN IS REMOVED AND DIELECTRIC CUT OFF FLUSH WITH FLANGE
1. USE ITEM 14 ON THREADS OF ITEM 9

NEXT ASSY	USED ON
46610H	

APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
XXX ±.005 XX ±.02
ANGLES ±0° 30' FINISH 63
EDGES & CORNERS .010 R MAX
MATERIAL

DR [signature] DATE 28 JAN 72
CHK [signature] 17 MAR 72
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HUGHES — HUGHES AIRCRAFT COMPANY, ELECTRON DYNAMICS DIVISION, TORRANCE, CALIF 90509

AMPLIFIER ASSY Ku BAND COAXIAL

SIZE D CODE IDENT NO 73293 DRAWING NO. B107734
SCALE 4/1 SHEET

B107734

Figure 8

FORM HAC-1185-C9-ED 2-69 REV. 12/70 DIETERICH-POST CLEARPRINT 1020H

While testing Ku-band diodes in the single-stage coaxial reflection amplifier circuit it was found that one watt with 3 dB gain over the required bandwidth could be obtained from one diode. It was decided to construct the Ku-band amplifier with three of these single-diode coaxial stages. The stages are circulator coupled with isolators between each stage. The final amplifier configuration is shown in Figure 9. The nominal stage gain figures shown include a .25 dB (maximum) loss per pass through the circulator junctions.

Diodes for the Ku-band amplifiers were selected and tested in the coaxial amplifier. The diodes have a breakdown voltage of 56 volts and capacitance values ranging from 1.3 picoforads for the driver stages to 1.9 picoforads for the output stages. Typical results of the tests at 15.0 GHz corrected for system losses are as follows:

STAGE NO.	RF POWER INPUT	RF POWER OUTPUT	BIAS VOLTAGE	BIAS CURRENT
1	10 mW	155 mW	68.8 V	95 mA
2	125 mW	616 mW	70.5 V	130 mA
3	400 mW	1080 mW	71.3 V	185 mA

A plot RF power out versus RF power in for each of the three stages is shown in Figure 10.

The total DC power into the three diodes is 28.7 watts which is somewhat below the specified maximum of 30 watts. The amplifier is supplied with current regulators for protection of the diodes. This is an extra feature which is provided and is not required by the specifications. The use of these regulators requires an additional 3 to 6 watts of DC input power.

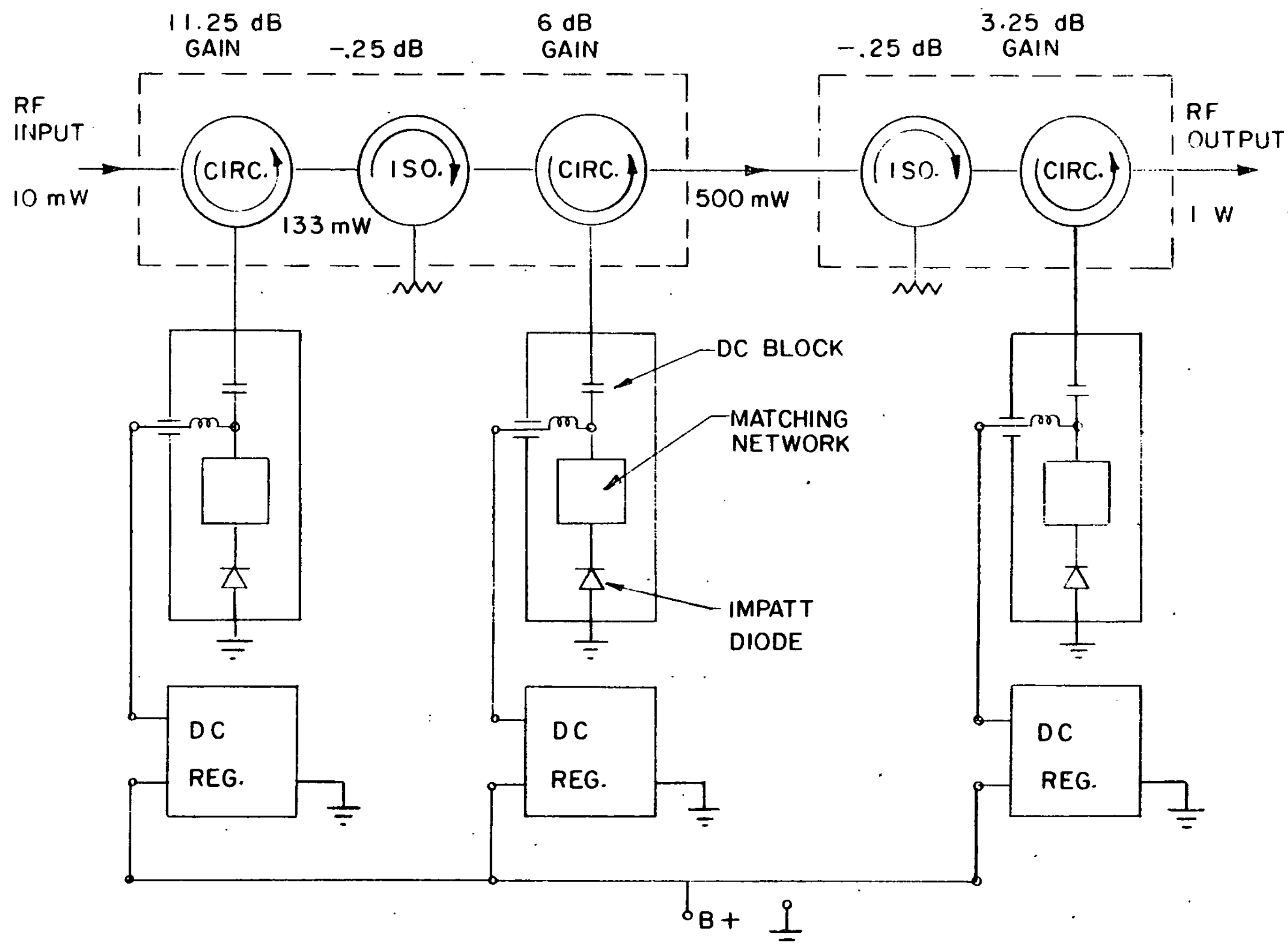

Figure 9 Ku-band amplifier configuration.

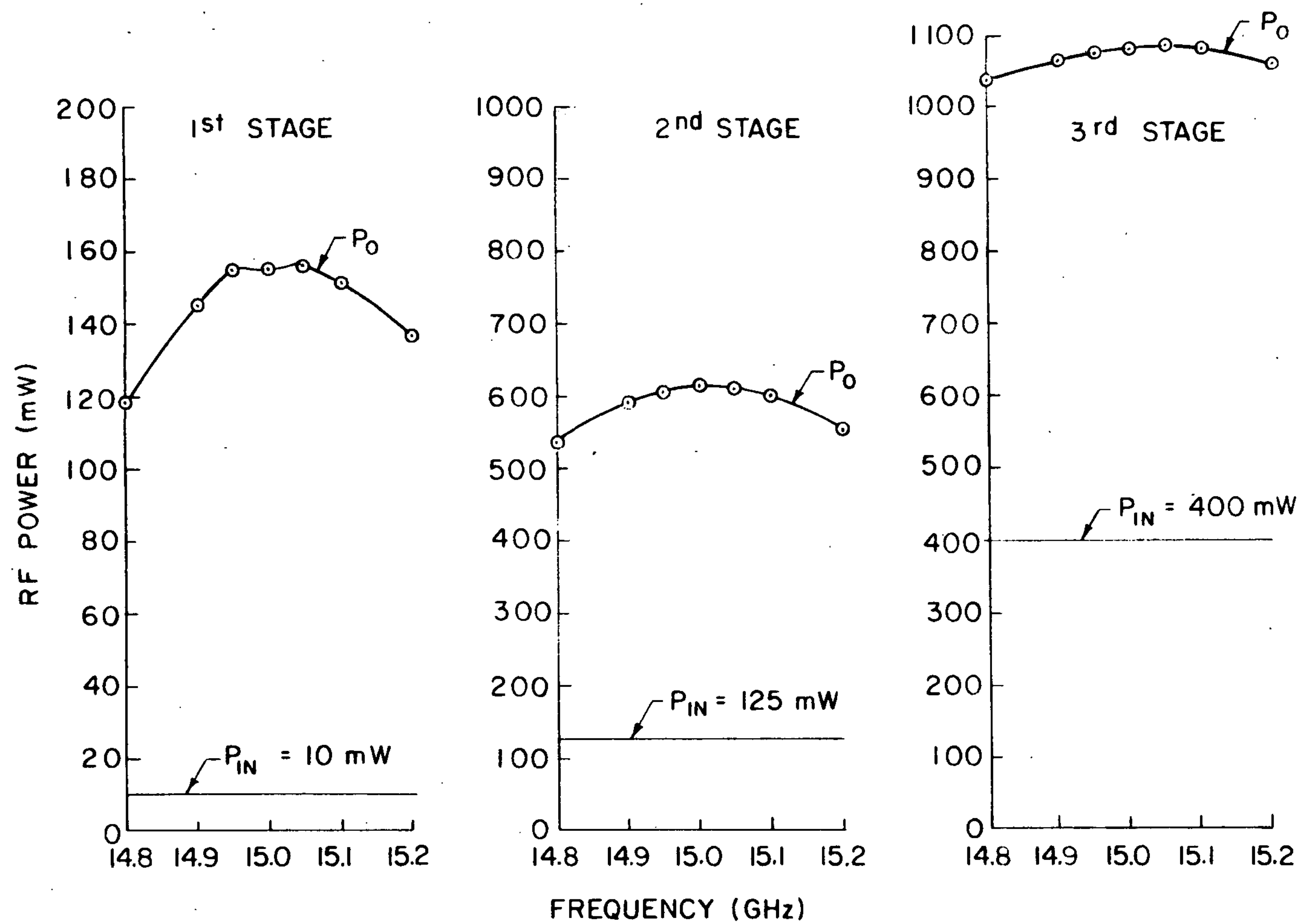

Figure 10 Amplifier stage characteristics.

The bias network, shown schematically in Figure 11, consists of shunt stub terminated in a large capacitance and a series open stub. The nominal electrical lengths of the stubs and the distance between them is 90^{o}. The shunt stub has an impedance of 132 ohms and is terminated in a 28 picoforad anodized aluminum bypass capacitor. The series stub has an impedance of 1 to 2 ohms and is DC insulated by using an anodized aluminum center conductor. The aluminum anodize layers used for DC insulation are of the "hard", Type III, kind. The impedance of the stubs were chosen so that the bias network would present a very low VSWR to the amplifier at 7.5 GHz as well as at 15 GHz in order to avoid subharmonic oscillations which could mix with the carrier and create spurious responses. The calculated VSWR of the network is less than 1.2:1 from 7 to 17 GHz and is less than 1.03 at 15 GHz.

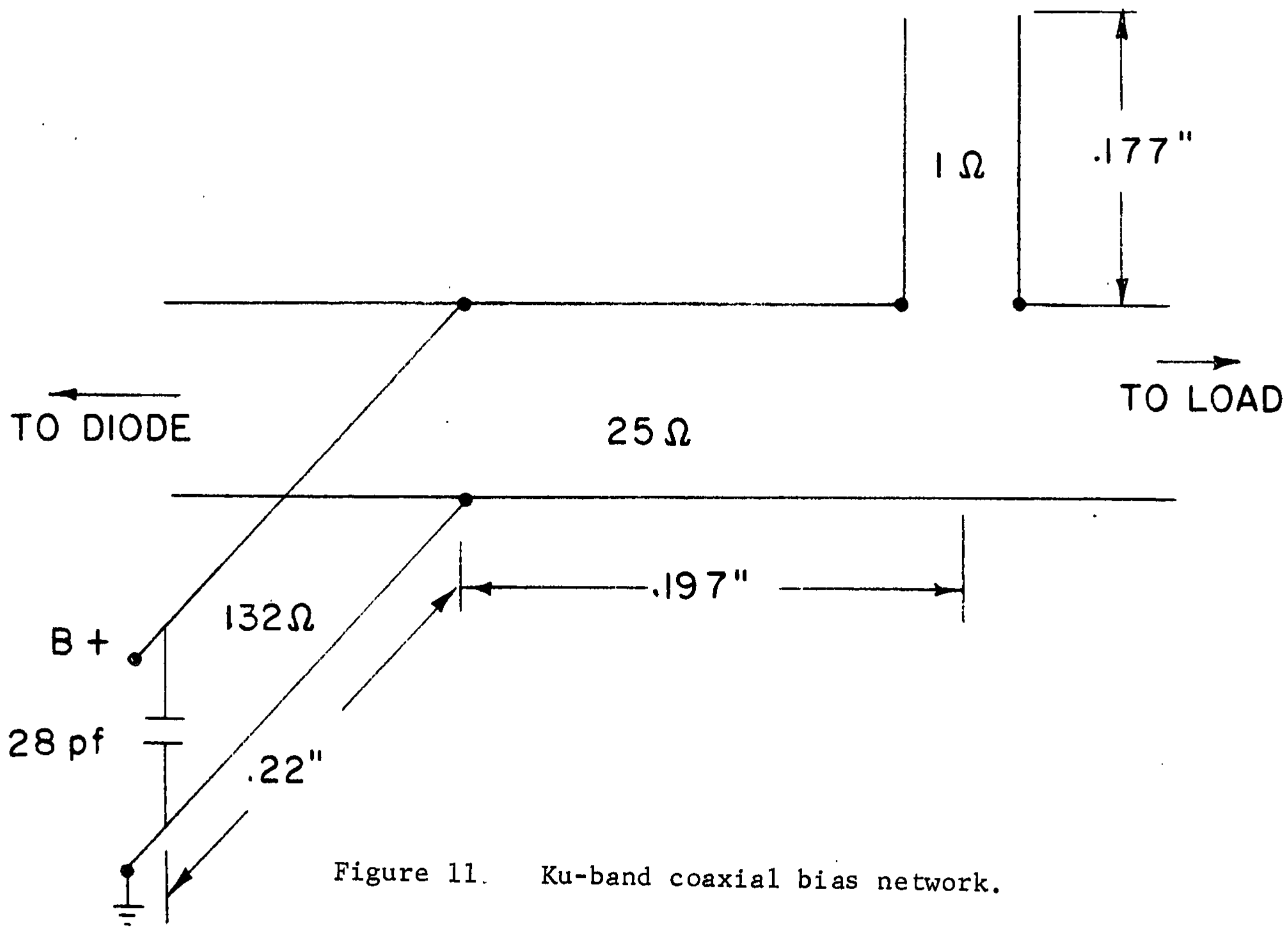

Figure 11. Ku-band coaxial bias network.

The DC regulators being supplied with the amplifiers are designed to give current regulation and overvoltage protection. A schematic diagram is shown in Figure 12.

Two four-port and two five-port isolator-circulator assemblies, Models KU20016 and KU20724 respectively, were purchased from E&M Laboratories, Westlake Village, California. They were ordered and tested to the following set of electrical specifications.

Frequency Range: 14.94 - 15.05 GHz
Insertion Loss: .25 dB max. per junction
Isolation: 23 dB min. per junction
VSWR (all ports): 1.20:1 max.
Operating Temperature: $-20^{o}C$ - $+70^{o}C$
Shielding: Magnetic

Another reflection amplifier studied was a two-diode IMPATT reflection amplifier which was pursued as a parallel approach to the two-diode transmission amplifier. This was done because of the inherently better gain-bandwidth product of the reflection amplifier even though it is more difficult to stabilize two diodes in a reflection circuit than it is in a transmission circuit.

The design procedures for single-diode reflection amplifiers are well established but can only be applied to two-diode amplifiers in a limited way. The procedures do not predict instabilities arising from a small conductance presented to the diode by the other diode or other mutual coupling effects. The procedure used to design a waveguide reflection amplifier is as follows. Modeling the waveguide as a two-wire transmission line, the input impedance of the diode and its coupling structure are calculated. The parallel combination of two of these impedances is brought into resonance with a shorted length of line. A length of line and a shunt susceptance (inductive iris) are added to provide the necessary

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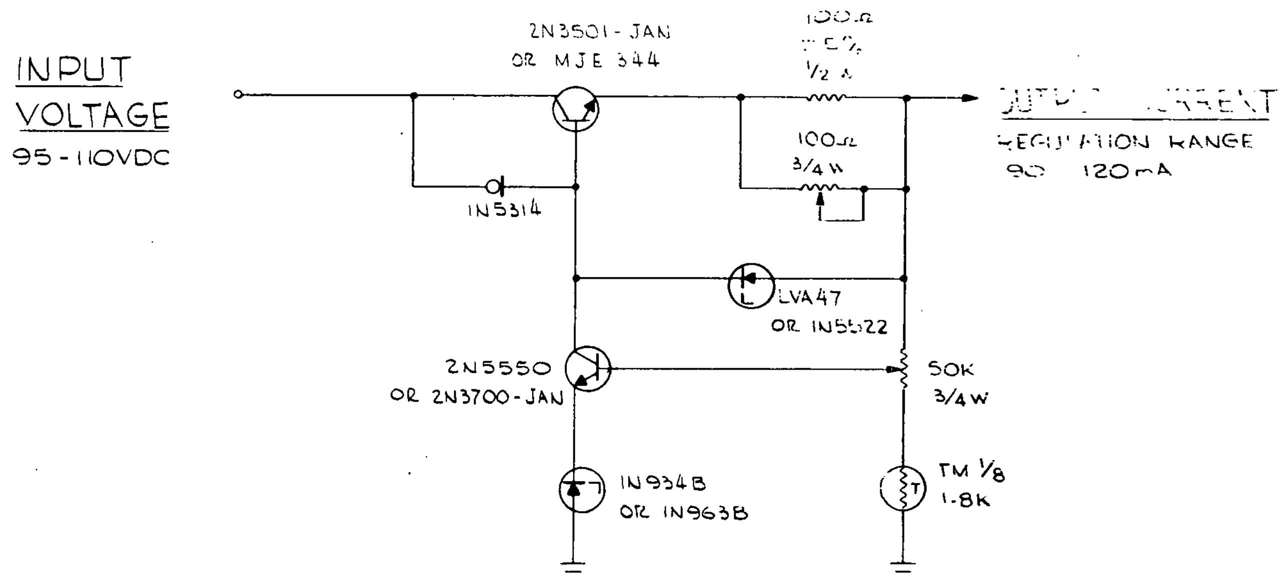

Figure 12

NOTES:

1. OVER VOLTAGE PROTECTION RANGE IS CONTROLLED BY 50K PCT

2. CURRENT REGULATION RANGE IS CONTROLLED BY 100Ω PCT

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QTY REQD	CODE IDENT.	PART NO. OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	FIND NO.

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
.XXX ±.005 .XX ±.02
ANGLES ±0° 30' FINISH 63/
EDGES & CORNERS .010 R MAX.
MATERIAL

NEXT ASSY	USED ON
APPLICATION	

		DATE
DR		8 OCT 71
CHK		25 OCT 71
		14 Oct 71
APPD		10-25-71

HUGHES
HUGHES AIRCRAFT COMPANY
ELECTRON DYNAMICS DIVISION
TORRANCE, CALIF. 90509

SCHEMATIC DIAGRAM, IMPATT CURRENT REGULATOR

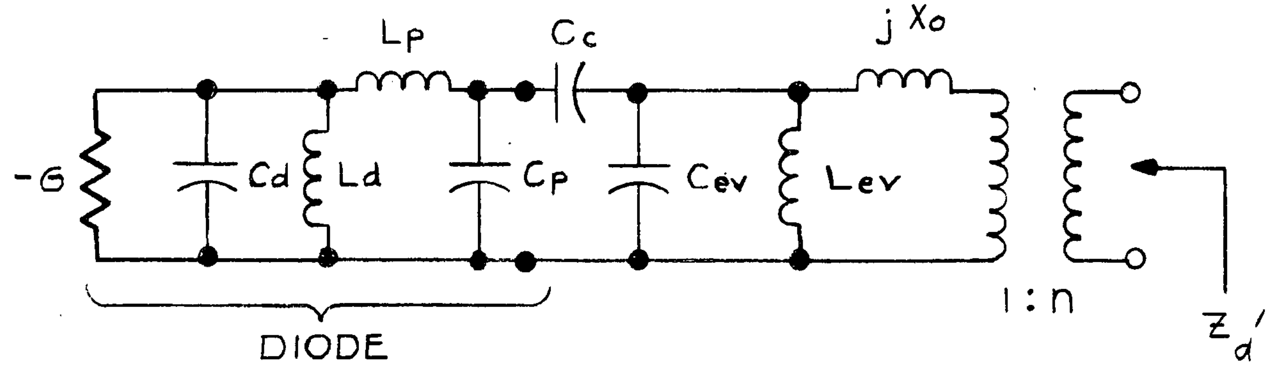
SIZE	CODE IDENT NO.	DRAWING NO.
C	73293	B106629

SCALE | SHEET

FORM HAC-11064-CS-ED 2-69 REV. 8/70 DIETERICH-POST CLEARPRINT 1000H impedance inversion for the desired gain and bandwidth. The resulting structure is then analyzed by computer from two points of view. The first is from the input port to check that the desired performance has been theoretically achieved. The second is from the diode's negative conductance, $-G_d$, to check whether the circuit is stable.

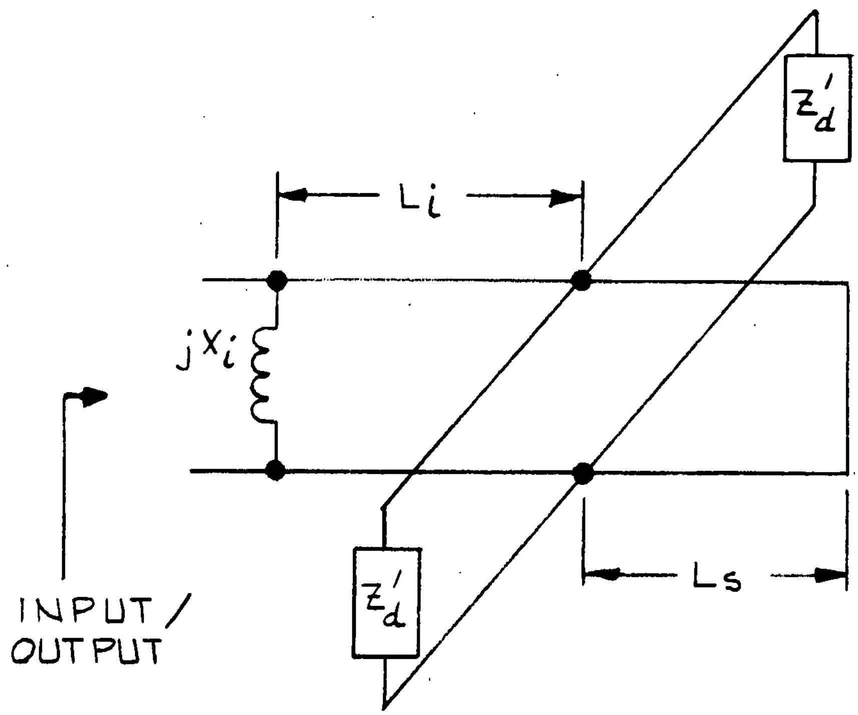
The equivalent circuit of the diode and its coupling structure is shown in Figure 13. It includes a transformer due to the fact that the diode is offset from the center of the waveguide, a tuning post inductance and shunt reactance, the series coupling capacitance to the diode, and the diode itself including package parasitics. The equivalent circuit of the entire amplifier is shown in Figure 14. The computer analysis of a similar X-band amplifier is shown in Figure 15. The initial theoretical work was done in X-band because characterization of the Ku-band diodes had not been completed. The X-band results predict 11 dB gain with 93 MHz, 1 dB bandwidth. The same design, scaled to 15 GHz, would give 150 MHz bandwidth.

The mechanical structure of the two-diode reflection amplifier is shown in Figure 16. An effort was made to incorporate as much tuning flexibility as possible into this circuit. The distance between the diodes and the inductive iris can be varied by putting in different spacers which are short lengths of waveguide. Any one of a number of different size irises, covering a large range of inductive reactance, may be used. Steps were machined at the iris and spacer junctions to assure good RF contact. Tuning posts vary the series coupling capacitance to the diode and a sliding short varies the diode to short distance. A three-screw tuner was designed to place between the amplifier and its circulator. It gives an additional degree of freedom in tuning the amplifier.



$-G_d, C_d, L_d$	IMPATT DIODE EQUIVALENT CIRCUIT
L_p, C_p	PACKAGE PARASITICS
C_c	TUNING POST COUPLING CAPACITANCE
C_{ev}, L_{ev}	EVANESCENT MODE REACTANCES DUE TO POST
jX_o	POST INDUCTANCE
n	TRANSFORMATION DUE TO DIODES OFFSET FROM CENTER

Figure 13   Equivalent circuit of diode and coupling structure.



Ls — DISTANCE FROM DIODE PLANE TO WAVEGUIDE SHORT

Li — DISTANCE FROM DIODE PLANE TO INDUCTIVE IRIS

jXi — INDUCTIVE IRIS SHUNT REACTANCE

Figure 14   Waveguide reflection amplifier equivalent circuit.

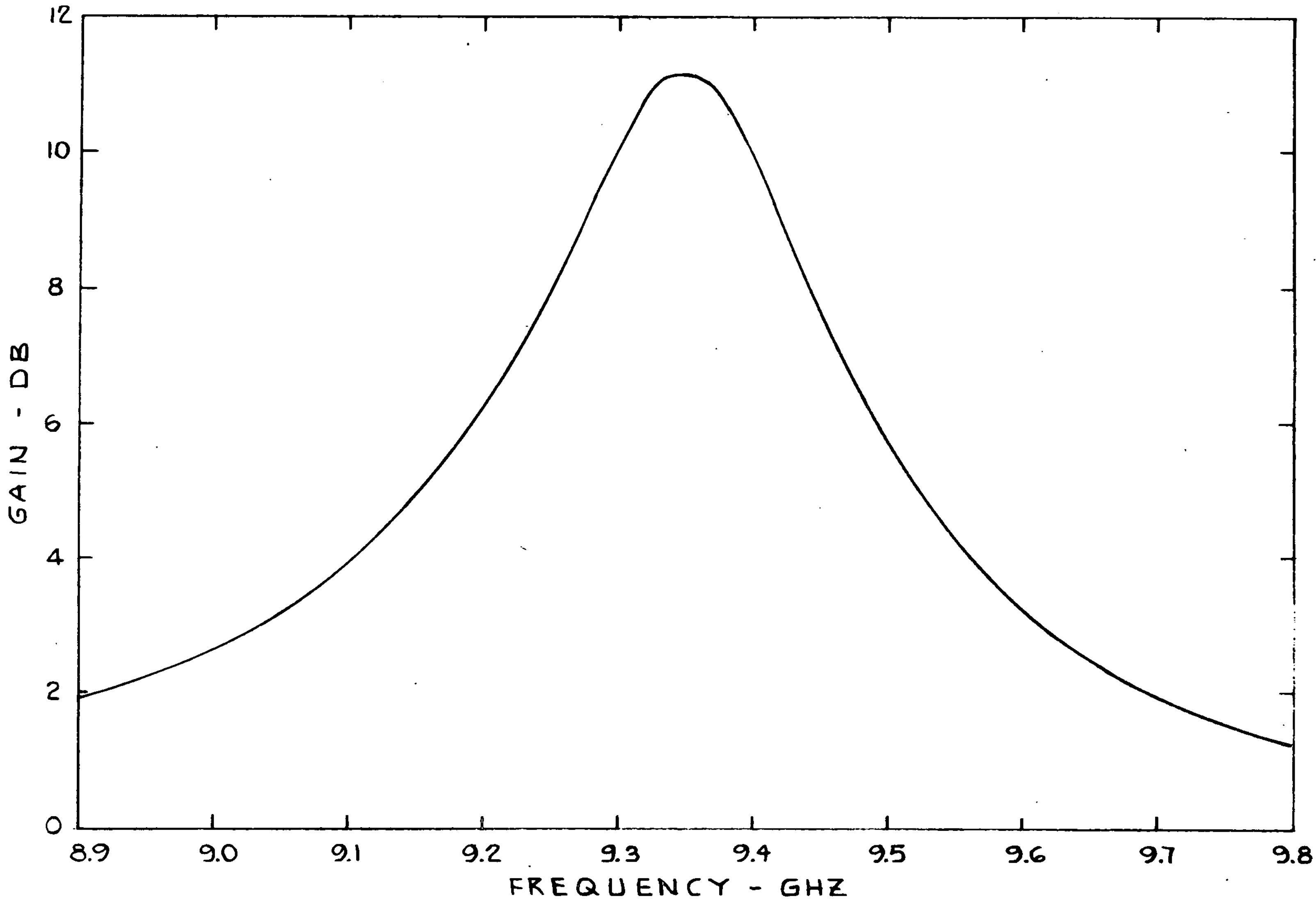


Figure 15 Theoretical performance of two diode X-band waveguide reflection amplifier.

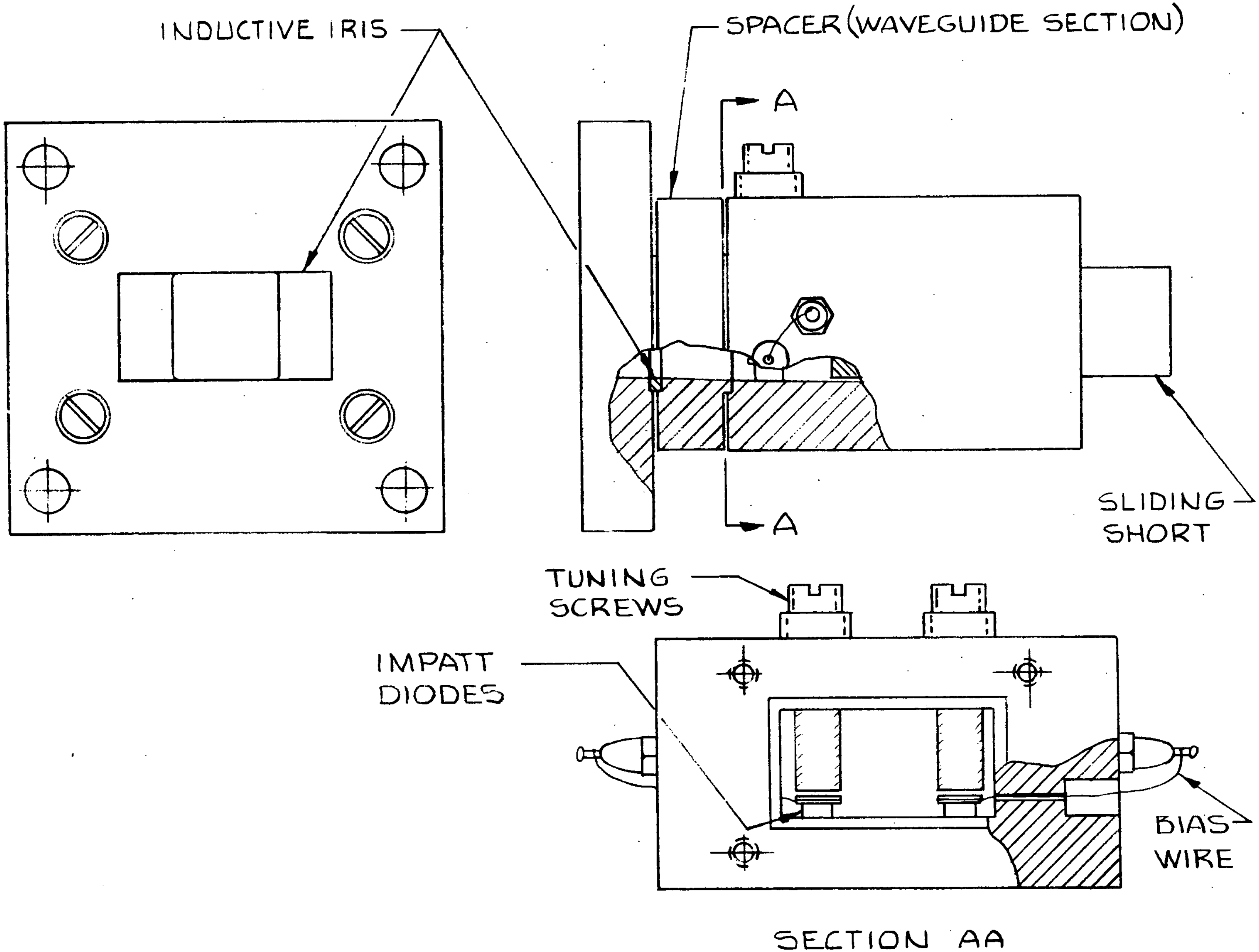


Figure 16 Ku-band two-diode waveguide reflection amplifier.

Bias is supplied to each diode separately by a .010 inch diameter insulated wire. The wire passes through a .015 inch diameter hole which is one-quarter wavelength long, then through a much larger diameter hole. This arrangement effectively isolates the RF signal from the dc circuitry.

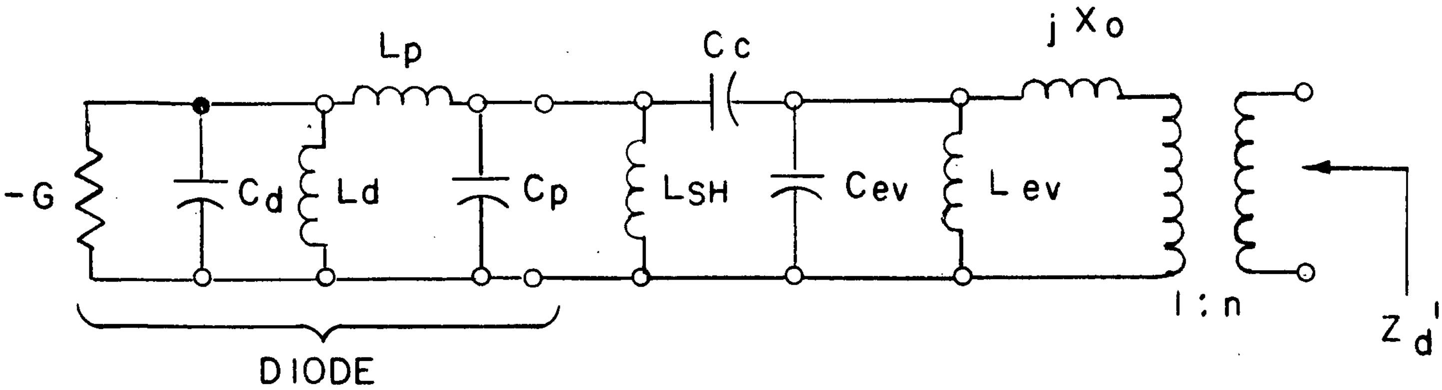
This circuit is similar to one described by Noisten[4] who achieved 7 dB gain at 700 mW output power and 3 dB gain at 1.4 watts output. One of these circuits was constructed and tested. Some small signal results obtained at 15 GHz with 20 mW drive include the following:

GAIN	POWER OUTPUT	1 dB BANDWIDTH
7.2 dB	90 mW	.58 GHz
10.0 dB	180 mW	.34 GHz
11.6 dB	260 mW	.24 GHz

Computer analysis of the two-diode Ku-band waveguide reflection amplifier was carried out and progressed to the point of having agreement between the mathematical model and experimental results. This was accomplished by modifying the model to include a shunt inductance due to the bias wire at the diode terminals. The modified equivalent circuit of the diode and its coupling structure is shown in Figure 17. The overall amplifier equivalent circuit remains unchanged and is shown in Figure 14. A typical computed response is shown in Figure 18. The diode parameters used for the analyses were:

$$-G = -.004 \text{ mhos}$$
$$C_d = .33 \text{ pF}$$
$$L_d = 1.08 \text{ nH.}$$

Large signal experimental testing of the two-diode reflection amplifiers did not yield acceptable results. Obtaining reasonable large signal gain and stability simultaneously was very difficult. Continued work on this circuit did not solve its stability problems and for this reason it did not perform as well as the single diode coaxial circuit.



$-G_d$, C_d, L_d,	IMPATT DIODE EQUIVALENT CIRCUIT
L_p, C_p	PACKAGE PARASISTICS
L_{SH}	BIAS WIRE INDUCTANCE
C_c	TUNING POST COUPLING CAPACITANCE
C_{ev}, L_{ev}	EVANESCENT MODE REACTANCES DUE TO POST
jX_o	POST INDUCTANCE
n	TRANSFORMATION DUE TO DIODES OFFSET FROM CENTER

Figure 17 Equivalent circuit of diode and coupling structure.

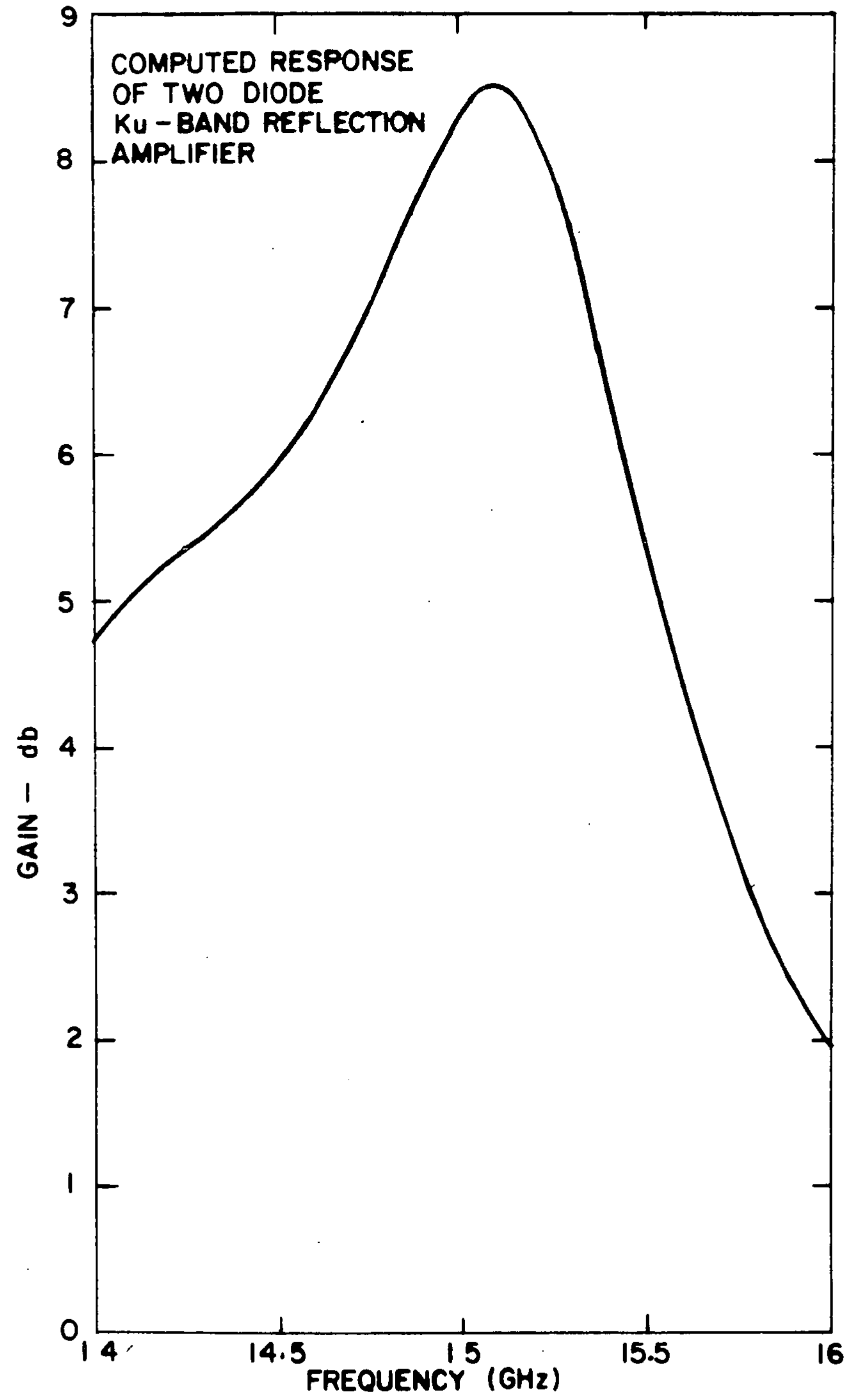


Figure 18 Computed response of two-diode Ku-band reflection amplifier.

TRANSMISSION AMPLIFIERS

The basic structure for a waveguide transmission amplifier is shown in Figure 19. In this structure IMPATT diodes are shunt mounted between matching irises in reduced height waveguide. Microwave energy enters one end of this structure, is amplified while it travels along the guide, and exits from the other end. Unlike a reflection amplifier, this amplifier has two ports and does not require a circulator to separate incoming and outgoing waves. Design techniques for this type of amplifier were developed under Air Force contract F33615-69-C-1787 and are described in some detail in a paper on the subject.[5] Using the same procedures and the diode characteristics mentioned before, we designed such an amplifier for use in Ku-band. In this band we found that the diode loads the guide very heavily, which requires very close spacing of the irises. Because of this it was difficult to get a good enough design to use in starting the automatic optimization routine that is used in the design of these amplifiers. This program is such that a reasonably good starting design is required before it can successfully optimize the amplifier to the best design under a given set of constraints. For this reason the design took somewhat longer than was expected.

The resulting configuration and calculated gain response is shown in Figure 20. We purposely maintained a fairly low gain-large band-width characteristic for this amplifier for two reasons. One is that this yields the most stable amplifier configuration, and the other is that this is to be used as the output stage at high power levels. The low gain amplifier will yield better gain saturation characteristics than will a high gain amplifier.

Test results on the two-diode transmission amplifier were disappointing. It was found that the computer design configuration using unpackaged diodes in waveguide filter cavities is unstable. Changing iris openings did not significantly improve the response.

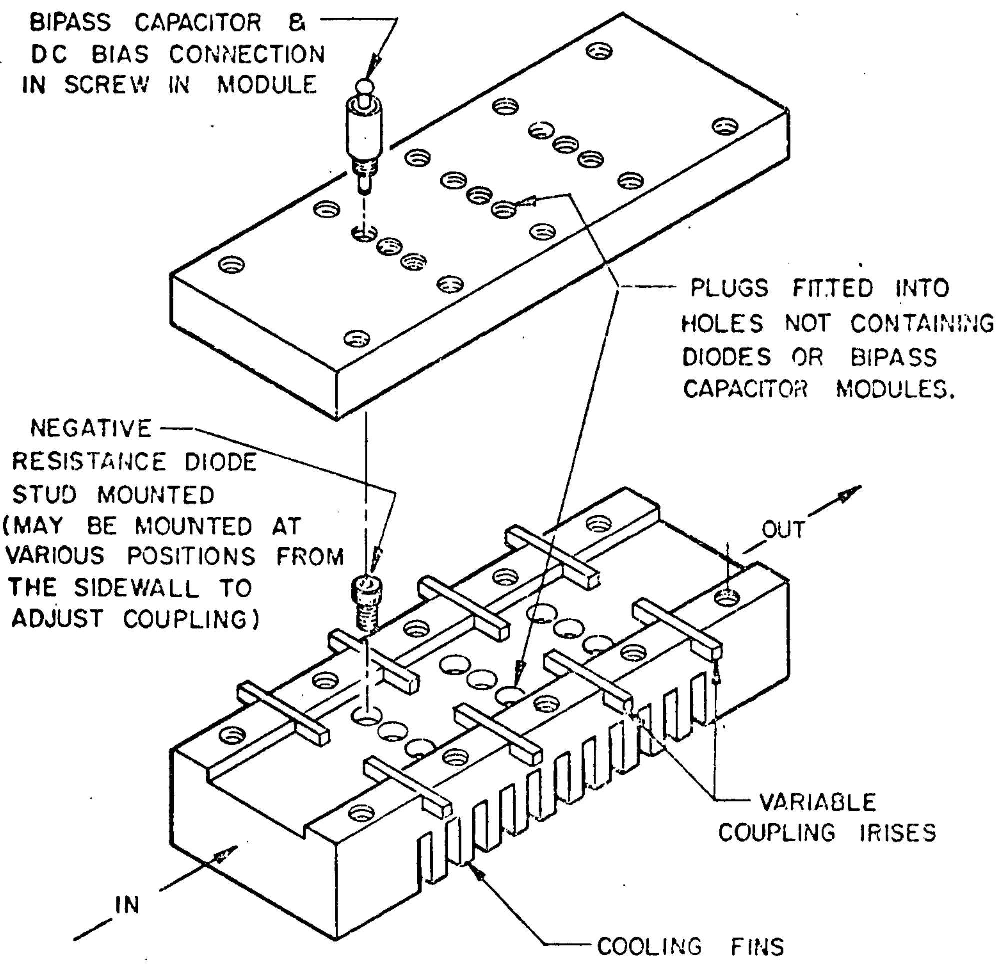


Figure 19 Three diode transmission amplifier.

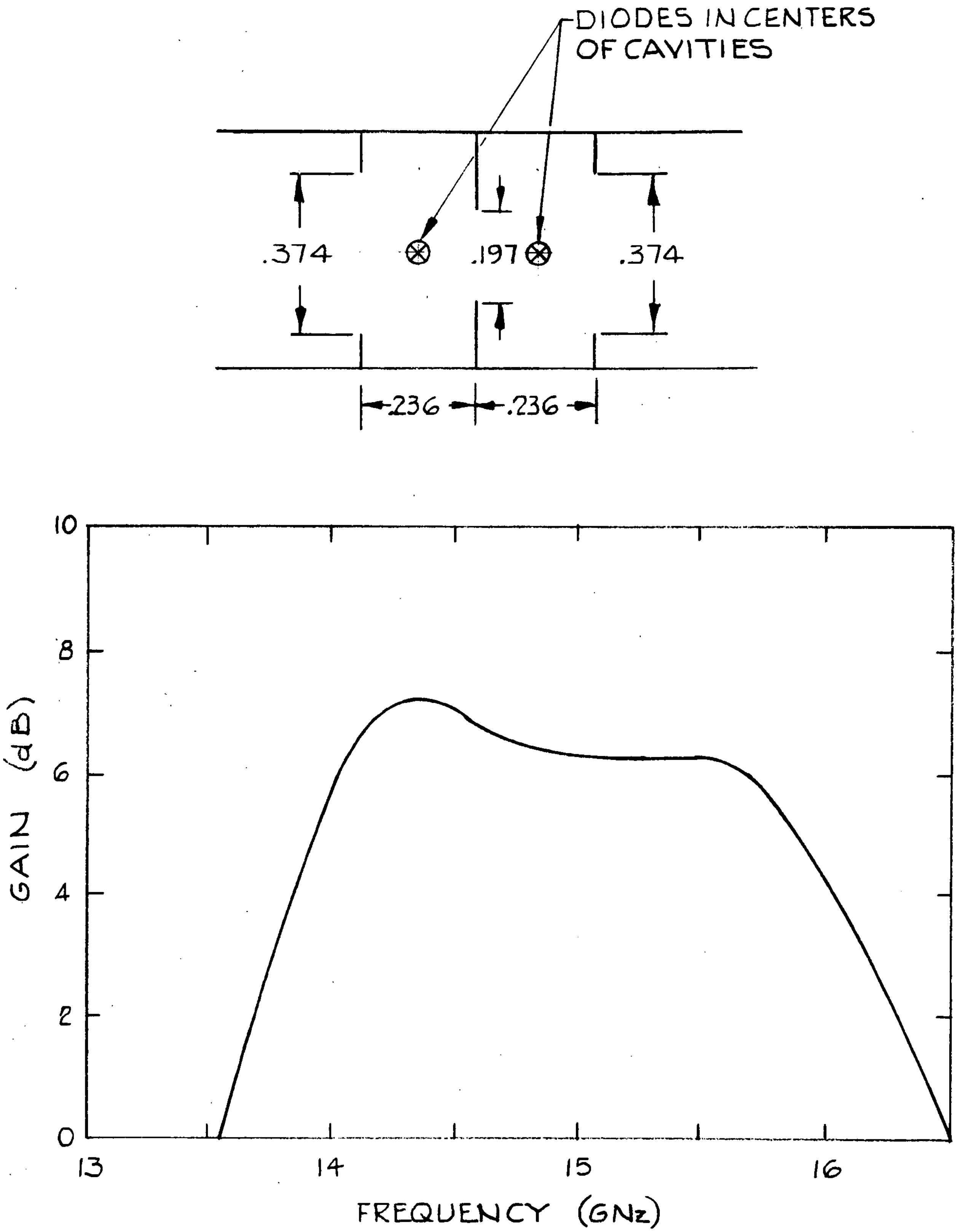


Figure 20 Configuration and gain response of two diode transmission amplifier.

Continued testing of this circuit with improved diodes did not yield satisfactory performance but gave useful information which lead to further experimentation. It was found that packaged diodes perform nearly as well as unpackaged ones in this circuit. Configurations other than the computer designed one were tried. Two of these which showed promise appear in Figure 21. In Figure 21a a $\lambda g/2$ length of line was added to each cavity. In Figure 21b the diodes are brought into resonance by inductive irises rather than in waveguide filter cavities. The latter circuit requires additional matching irises which are not shown. In order to obtain more tuning flexibility the circuit was modified to provide tuning screws in the iris planes of configuration 21a.

Further investigation did not yield a stable configuration with reasonable large signal gain. For this reason two single diode coaxial amplifier stages were substituted for the two diode transmission amplifier in the final unit.

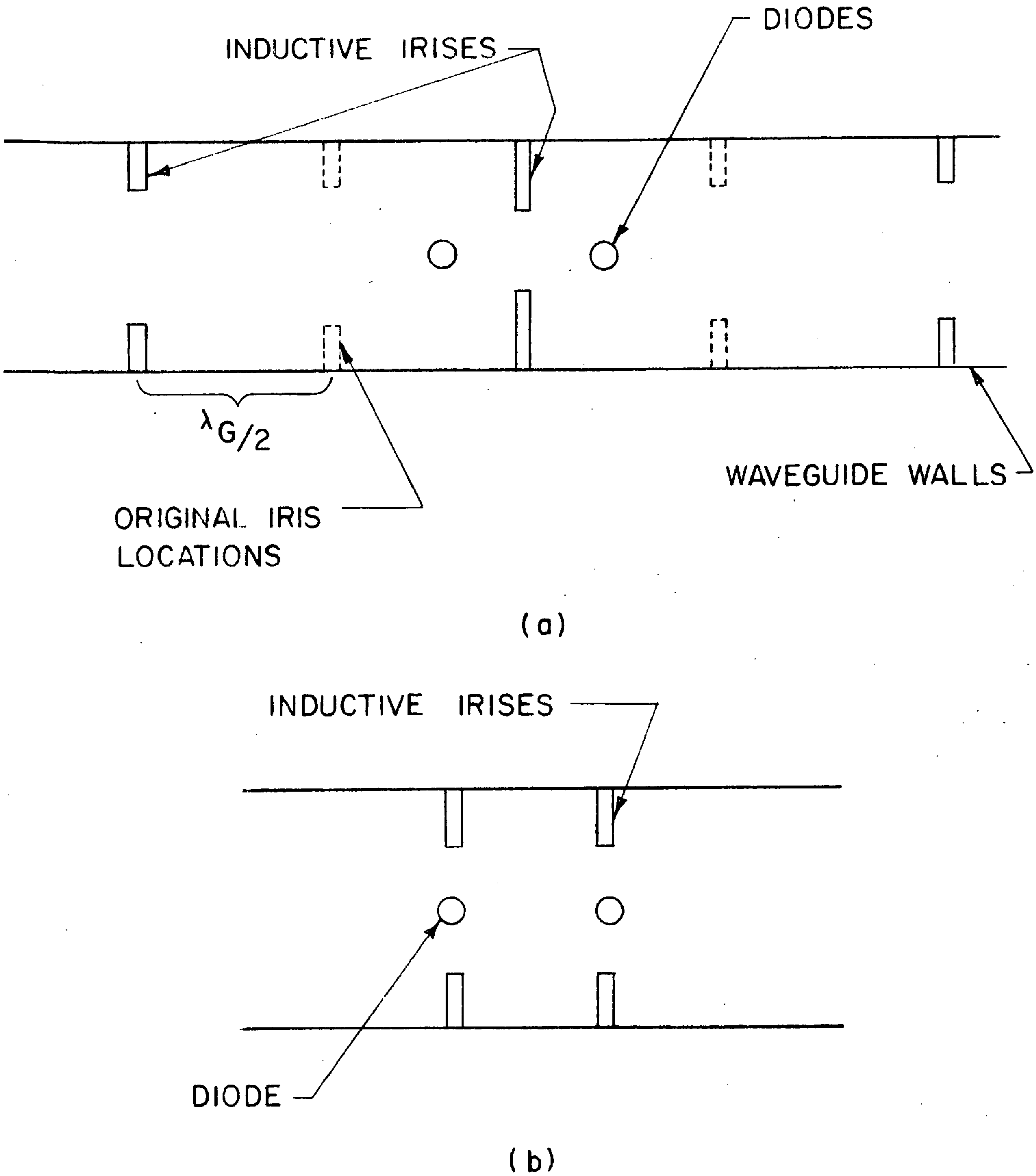


Figure 21 Experimental transmission amplifier configuration.

AMPLIFIER PERFORMANCE

This section summarizes the performance of two three-stage Ku-band amplifiers (S/N's 001 and 002) which were shipped in December, 1971. Gain versus frequency is plotted for both amplifiers in Figure 22. The RF power input for these curves is a constant 10 mW. It can be seen that both amplifiers will exceed the specified 20 dB center frequency gain and 100 MHz, 1 dB bandwidth.

The gain characteristics at 14.90 GHz and 15.00 GHz are plotted for the two amplifiers in Figures 23 and 24. The amplifiers are highly saturated at the one watt output level which is to be expected because of the non-linearities of IMPATT diodes. Regions of $\pm 1/2$ dB gain linearity are found at smaller drive levels and are indicated in the figures.

Data sheets which were shipped with the two amplifiers are shown in Figures 25 and 26. The data sheets, in addition to the nominal gains and frequencies, give the operating currents and voltages of the amplifiers and the bias points of the individual diodes (with 10 mW RF drive).

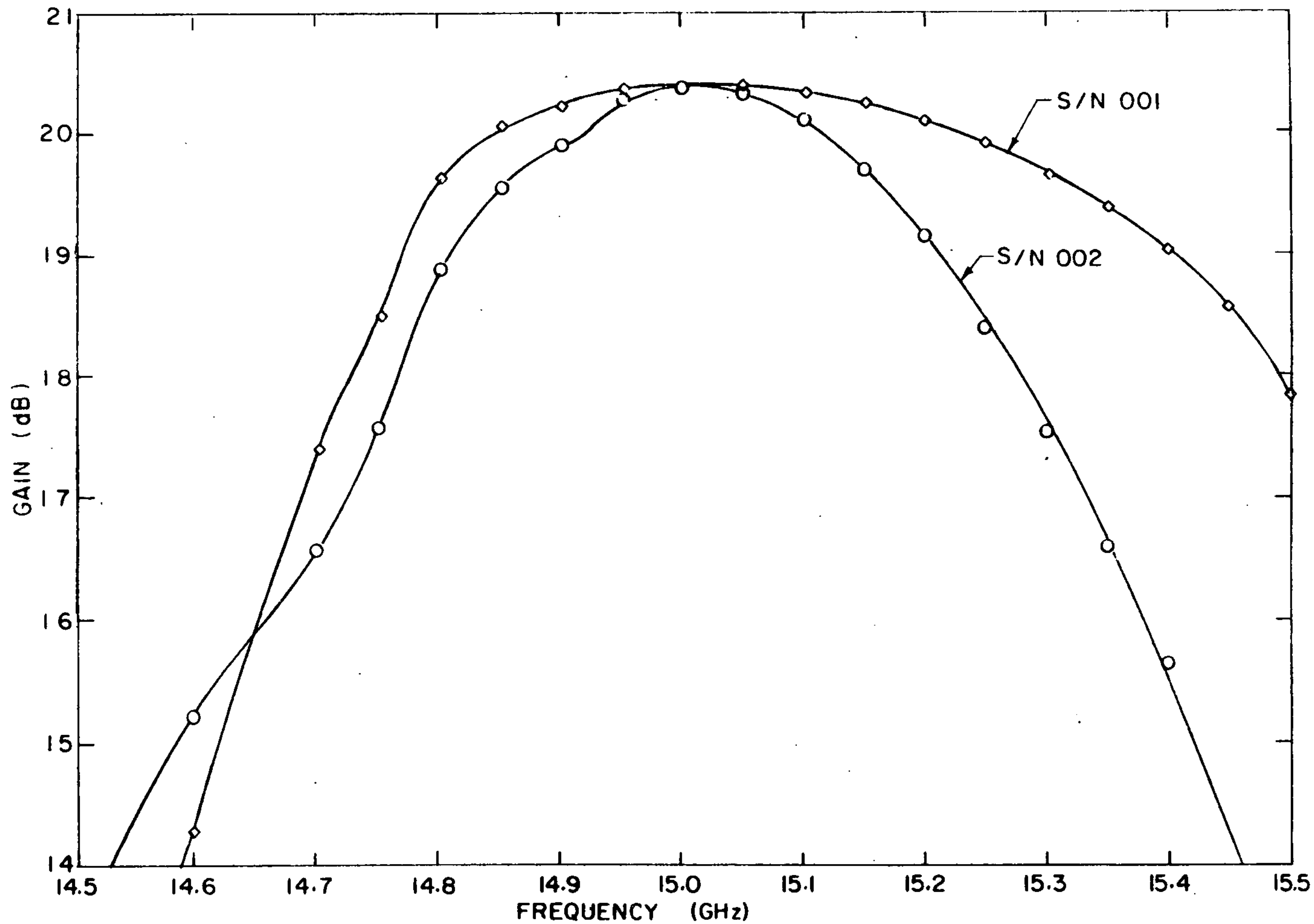


Figure 22 Gain vs. frequency for 46610H Ku-band amplifiers.

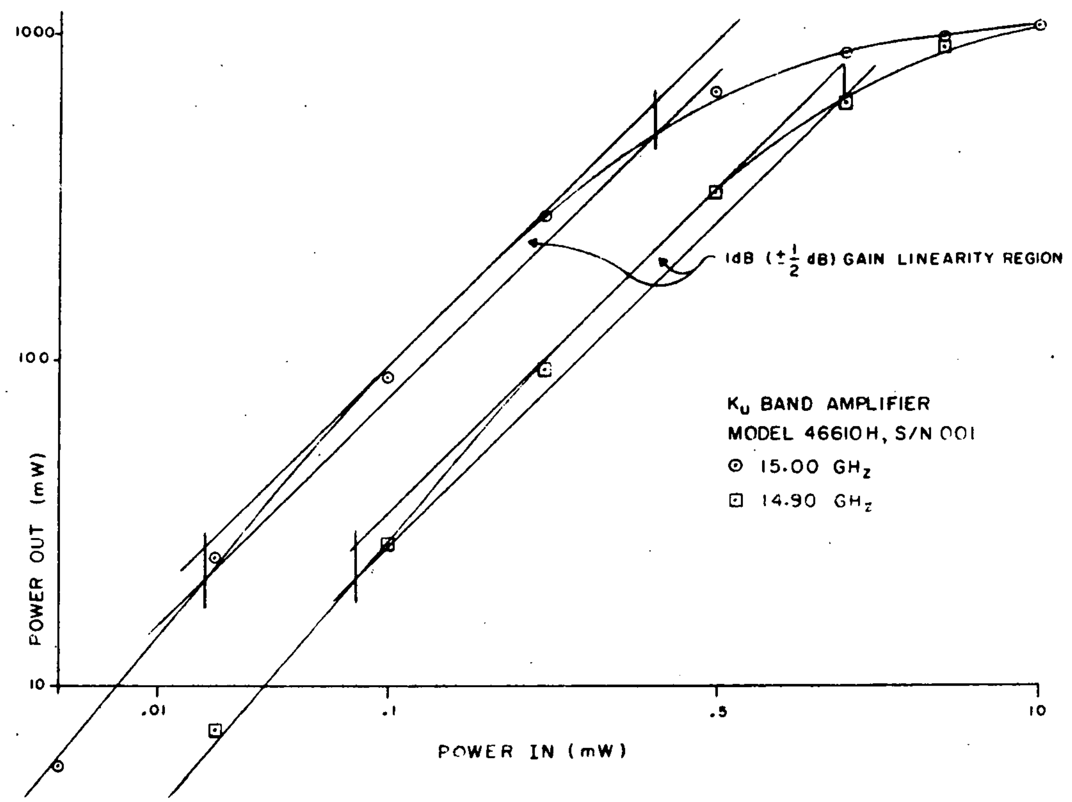


Figure 23 Ku-band amplifier gain characteristics; S/N 001.

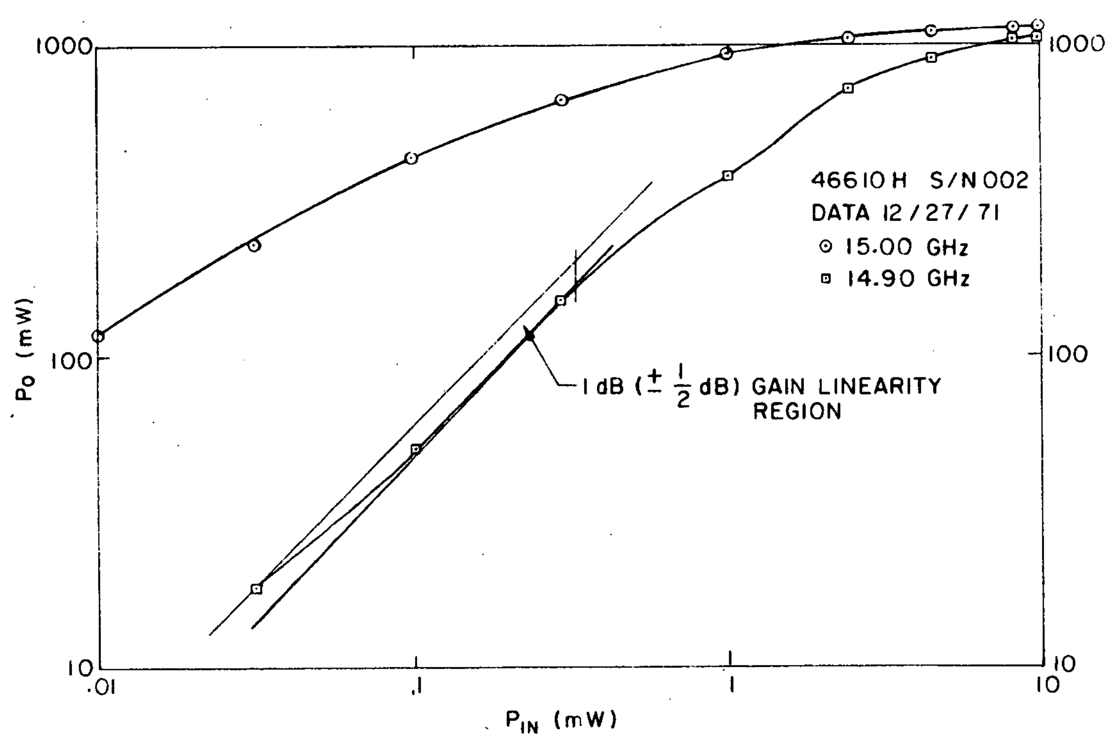


Figure 24 Ku-band amplifier characteristics; S/N 002.

MODEL 46610H

THREE STAGE KU-BAND IMPATT AMPLIFIER

DATA SHEET

S/N: 001
S/O:
DATE: 12/7/71

Amplifier Characteristics

Operating Frequency Range	14.95 - 15.05 GHz
Gain with 10 mW input	20.25 dB min. (14.95 - 15.05 GHz) 20 dB min (14.90 - 15.20 GHz)
Amplifier Operating Voltages & Currents	+80.0 ± 0.5 Volts at 408 ma typ.
Diode Operating Voltages & Currents with Mounting Plate Temp. at 30°C	First Stage 66.8 Volts / 95 ma
	Second Stage 71.3 Volts / 125 ma
	Third Stage 68.2 Volts / 178 ma
Total DC Power Into Diodes	27.5 Watts

Caution

When applying voltage, do not exceed above specification.

Operation

For best performance, unit should be maintained at 30°C by mounting to a heat sink or cooling with forced air.

Figure 25 Data sheet.

MODEL 46610H

THREE STAGE KU-BAND IMPATT AMPLIFIER

DATA SHEET

S/N: 002
S/O:
DATE: 12/28/71

Amplifier Characteristics

Operating Frequency Range	14.95 - 15.05 GHz	
Gain with 10 mW Input	20.25 dB min. (14.95 - 15.05 GHz) 20 dB min (14.92 - 15.11 GHz)	
Amplifier Operating Voltages & Currents	+80.0 ± 0.5 Volts at 410 ma typ.	
Diode Operating Voltages & Currents with Mounting Plate Temp. at 30°C	First Stage	65.9 Volts / 95 ma
	Second Stage	69.4 Volts / 121 ma
	Third Stage	70.7 Volts / 182 ma
Total DC Power Into Diodes	27.5 Watts	

Caution

When applying voltage, do not exceed above specification.

Operation

For best performance, unit should be maintained at 30°C by mounting to a heat sink or cooling with forced air.

Figure 26 Data sheet.

OUTLINE AND MOUNTING

The outline and mounting details for the Ku-band amplifier are shown in Figure 27. The three amplifier stages, two circulator assemblies and three DC regulators are mounted to an aluminum plate. This mounting plate should be secured by the user to a heat sink using four No. 6-32 screws. The heat sink should be capable of removing at least 30 watts from the amplifier and should maintain the mounting plate temperature between -20°C and 70°C.

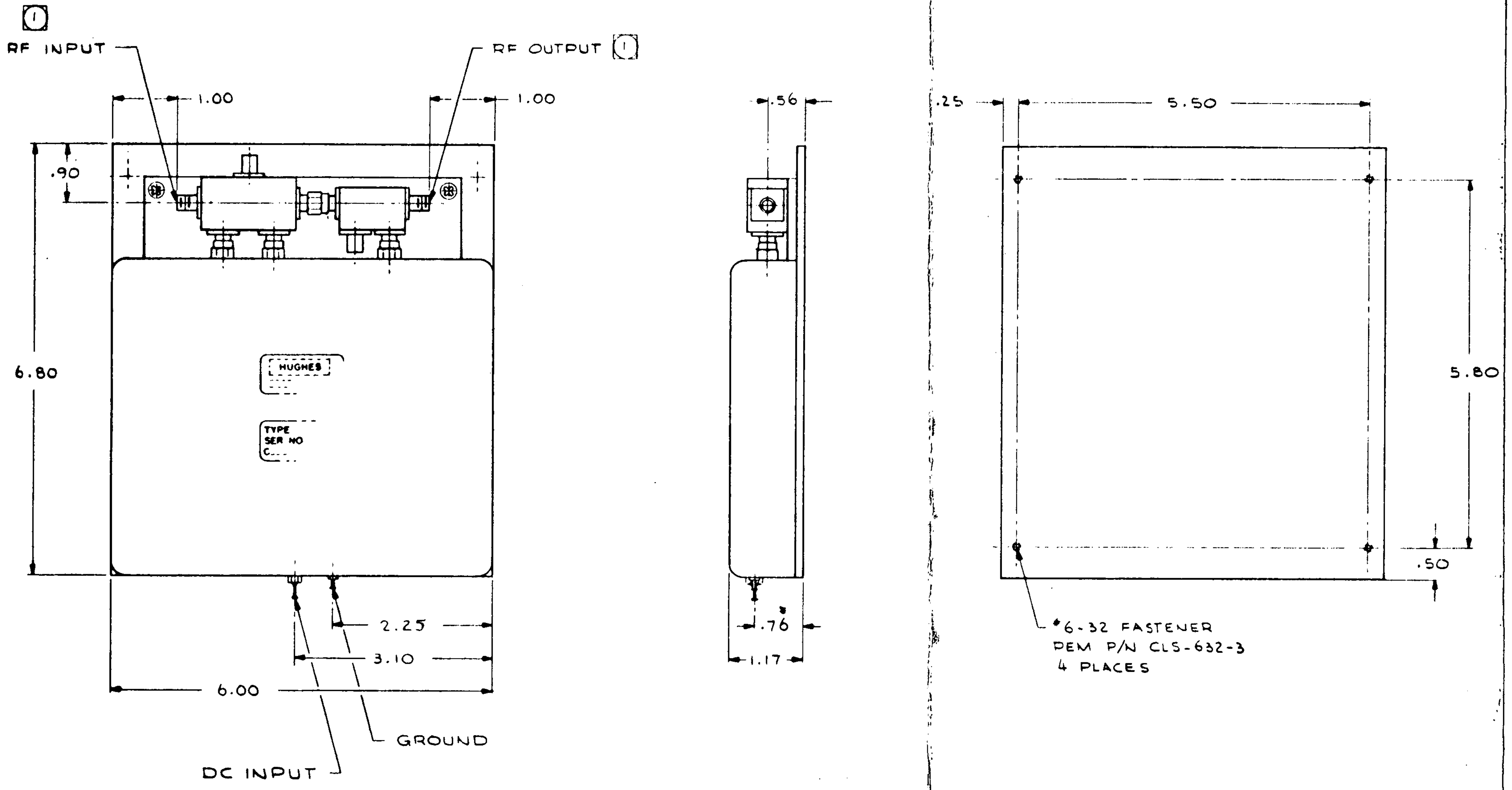
It may be noted that the volume occupied by the amplifier is slightly larger than the approximate 4 inch x 4 inch x 2 inch volume called for in the specifications. Similarly, the weight is expected to be somewhat heavier than the approximate 14 ounces called for. These slight increases are primarily due to the fact that an extra feature, current regulation, has been included in the amplifier package.

The aluminum cover is made from a standard sized aluminum box and secured to the mounting plate.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

PART NO. B107244.001



NOTES:

1 RF INPUT & OUTPUT CONNECTORS ARE SMA FEMALE OR EQUIVALENT

Figure 27

REVISIONS						
EFF	AUTHORITY	ZONE	LTR	DESCRIPTION	DATE	APPROVED

RELEASED PRINT ENG DOC CONTROL CTR 1A 3-17-72

QTY REQD	CODE IDENT	PART NO OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	ZONE	FIND NO

PARTS LIST

NEXT ASSY	USED ON
	46610H

APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES .XXX ± .005 .XX ± .02 ANGLES ± 0° 30' FINISH 63 EDGES & CORNERS .010 R MAX

MATERIAL

DR [illegible] 10 NOV 71

CHK [illegible] 11 MAR 72

APPD H C Bowen 3/17/72

HUGHES — HUGHES AIRCRAFT COMPANY, ELECTRON DYNAMICS DIVISION, TORRANCE, CALIF 90509

INSTALLATION CONTROL DWG
Ku-BAND AMPLIFIER
MODEL NO. 46610H

SIZE D CODE IDENT NO 73293 DRAWING NO B107244

SCALE 1/1 SHEET

38

FORM HAC 1108-CS-ED 2-69 REV. 2/69 DIETERICH-POST CLEARPRINT 1000H

B107244

CONCLUSIONS

The coaxial amplifier works quite well and its performance agrees well with design predictions. Neither the two diode waveguide reflection or transmission amplifier work as well as designs had predicted. Obtaining reasonable gains and stability simultaneously was difficult with both of these circuits.

Because of this and because the diode test results were better than expected, it was decided to use three coaxial stages to meet the required specifications.

It was found that three coaxial stages could achieve 1 watt output at 15 GHz with 20 dB (minimum) gain over greater than 100 MHz bandwidth. This approach uses the same number of diodes as the original reflection amplifier - transmission amplifier approach; hence, the DC to RF conversion efficiency is the same for both. The three diodes consume less than 30 watts of DC power.

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3. G. L. Matthaei, L. Young, and E.M.T. Jones, "Microwave Filters, Impedance Matching Networks, and Coupling Structures," McGraw-Hill Book Company, Inc., New York, 1964.

4. J. Noisten, "Avalanche Diode Power Amplifier for Ku-band," 1970 IEEE Solid State Circuits Conference Digest, pp. 16-17, Feb. 1970.

5. H. C. Bowers, T. A. Midford, and S. T. Plants," IMPATT Diode Multistage Transmission Amplifiers," IEEE Trans. on MTT, MTT-18, pp. 943-951, November 1970.